A Ballooned Wireless Mesh Network for Disaster Response

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• East Japan Great Earthquake in March 11th in 2011 caused severe damage over the wide area of Northern Japan.
• 5,841 persons died and 3,490 are missing due to the great tsunami
• The tsunami destroyed power supply, information systems and communication lines on the ground
• It is strongly required to quickly reconstruct emergency network
  - to recover from disorder
  - to provide urgent hotspot at evacuated places
  - to connect to Internet and regional intranet
  - to provide information services for evaluated residents
Advantages of WLAN as disaster information network are
- Robust in case of disaster and less failure
- No cable disconnection,
- Quickly reconstruct network and establish the emergency information system just after occurrence of disaster
- Mobile communication environment using vehicles with WLAN to organize adhoc network

Disadvantages
- Limited Communication range : Max 2~5 Km (for IEEE802.11b/g)
- Signal distortion by influence buildings on the ground

Therefore, by installing WLANs to balloons and by multi-hopping those in the sky over ground, more useful disaster information can be realized
Introduction of Ballooned Wireless Mesh Network

- Both backbone and access networks can be established by multiple mesh points.
- In horizontal, backbone network can organize an adhoc network, while in vertical, each mesh point can support multiple MTA access.
- Thus, mesh network can deploy as a temporal emergency network covered on the disaster area by installing to balloons.
To construct wide-area wireless mesh network by combining balloons and Wireless mesh network (BWMN) for disaster information network:

- To prototype BWMN system using conventional commercially available WLANs such as IEEE802.11b/g/j
- To evaluate performance the BWMN prototype
- To offer various information service applications useful when disaster happened
  - Wide-area Disaster Information sharing System
  - Wireless IP telephone network
  - Ballooned wireless video surveillance network
BWMS as Disaster Information Network

Combination of Balloon and BWMS and multi-hopping

1) In case of Disaster at mountain village

2) In case of Disaster at city side
Although IEEE802.11s is standardized for mesh network, there is no commercial product.

We prototyped two BWMSs using current available standard LANs with different antennas:

- Type 1: combination of IEEE802.11j + IEEE802.11b/g
- Type 2: combination of IEEE802.11b + g
Characteristics of Type 1 BWMN

1) Horizontal (Back bone network)
   - Standards: IEEE802.11j
   - Power: 250mW
   - Data Transmission: 54Mbps
   - Antenna: 6 directions plane antenna (covered 360°)
   - Adhoc function: Automatic Network configuration with minimum spanning tree according signal power

2) Vertical (Access network)
   - Standards: IEEE802.11b/g
   - Power: 10mW
   - Data Transmission: Max 54Mbps
   - Antenna: co-linear antenna
System Architecture

WIDIS
VoIP
Video

Application

socket monitoring plane
port monitoring plane

monitoring module

route decision module
throughput accounting plane
sensing packet watching plane

connection management module

sender plane
receiver plane

sender / receiver module

TCP/UDP
IP
NIC0

TCP/UDP
IP
NIC1

TCP/UDP
IP
NIC2

TCP/UDP
IP
NIC3

Wireless Network

route list
policy list
list making GUI
Antenna Direction of Type 1

Horizontal Direction

Vertical Direction

70°

+5°

-5°
Characteristics of Type 2 BWMN

1) Horizontal (Back bone network)
   - Standards: IEEE802.11g
   - Power: 10mW
   - Data Transmission: 54Mbps
   - Antenna: 2 directions patch antennas (covered 180°)
   - Adhoc function: Automatic Network configuration with minimum spanning tree according signal power

2) Vertical (Access network)
   - Standards: IEEE802.11b/g
   - Power: 10mW
   - Data Transmission: Max 54Mbps
   - Antenna: plane antenna
Ballooned Wireless Mesh Network Node

- Balloon Part
  - Balloon 3.5m
  - Ropes

- Wireless Node
  - Connection rope
  - Control rope
  - Fixed frame
  - Access node
  - Supporting rope
  - LAN cable
  - Power cable
  - Anchor

- Support
Performance Evaluation of Type 1 BWMN

- Evaluation of transmission propagation characteristics
- Horizontal Direction (IEEE 802.11j, 4.9GHz) and Vertical Direction (IEEE 802.11b,g, 2.4GHz) with various parameters:
  - distance,
  - height difference,
  - signal power,
  - the No. of hoppings
  - antenna direction
  - wind influence
Transmission Characteristics: Type 1 BWMN
Horizontal (4.9GHz), Vertical (2.4GHz)

【Base Station】
- RADIUS Server
- FTP/DHCP Server
- Wireless-GW (GW7250)
- NAP-R (L3スイッチ)

Client PC (TestPC_A)
4.9GHz 250mW
⇔Throughput Test
①50m (1 Hop)

Client PC (TestPC_B)
4.9GHz 250mW
⇔Ping Test
②100m (2 Hop)

Height (h) = 0~10

Throughput Test
Ping Test

Wireless GW (GW7250)
Result of Propagation Characteristics: Type 1 BWMN
Horizontal Direction vs. RSSI and Packet Arrival Rate

Distance vs. Ave. RSSI [dB]
Sending Signal Power: 250mw

Distance vs. Packet Arrival Rate [%]
Sending Signal Power: 250mw

RSSI: Received Signal Strength Indicator)
Result of Influence of the Number of Hopping: Type 1 BWMN

The No. of Hopping vs. Throughput (Mbps)

The No. of Hopping vs. Response Time (ms)
Result of Influence of Shaking Access Point: Type 1 BWMS

- Shaking strongly sender and receiver AP by hand equivalent to 10 (m/s)
Performance Evaluation of Type 2 BWMN

- Evaluation of transmission characteristics
- Horizontal Direction (IEEE 802.11b,g, 2.4GHz) and Vertical Direction (IEEE 802.11b,g, 2.4GHz) with various parameters:
  - communication distance,
  - height difference,
  - antenna direction
Result of Propagation Characteristics: Type 2 BWMN
Throughput vs. Horizontal Distance for different antennas
Result of Characteristics: Type 2 BWMN
Throughput & Packet Loss Rate vs. Horizontal Distance

Throughput [Mbps]

Packet Loss Rate [%]

Distance between balloon and relay station [m]

Throughput & Packet Loss Rate vs. Horizontal Distance

Packet Loss Rate

Throughput
Performance Evaluation of WIDIS

Safety Information
Disaster Information
Lifeline information

Result:
50 users could access to WIDIS Server without performance degradation
Wide Area Disaster Information Sharing System

広域災害情報共有システム

災害名：東京直下地震（実証実験）

◆ 被害情報
  ［登録］身の回りの被害状況を登録します。
  ［閲覧］地域の被害状況に関する情報を閲覧します。

◆ 安否情報
  ［災害用伝言ダイヤル］
  ［ポード災害用伝言板サービス］
  ［AI安否確認システム］

◆ 気象・地震情報
  ［リンクする気象情報サイト］
  ［気象庁・地震情報］
  ［日本気象協会・地震情報］

◆ 道路・交通機関情報
  ［登録］道路・交通機関の被害・復旧に関する情報を登録します。
  ［閲覧］道路・交通機関の被害・復旧に関する情報を閲覧します。

◆ ライフライン情報
  ［登録］ライフラインの被害・復旧に関する情報を登録します。
  ［閲覧］ライフラインの被害・復旧に関する情報を閲覧します。

◆ 生活情報
  ［登録］避難生活で必要な情報を登録します。
  ［閲覧］避難生活で必要な情報を閲覧します。

◆ ボランティア活動情報
  ［登録］ボランティアの活動状況についての情報を登録します。
  ［閲覧］ボランティアの活動状況についての情報を閲覧します。

◆ ボランティア募集・参加希望情報
  ［登録］ボランティア募集・参加希望についての情報を登録します。
  ［閲覧］ボランティア募集・参加希望についての情報を閲覧します。
Performance Evaluation of Three Different Applications on BWLAN

We developed three different disaster applications:
- Wide-area Disaster Information sharing System based on Web GIS (WIDIS)
- Wireless IP telephone network
- Ballooned wireless omni-directional video surveillance System
Performance Evaluation of Mobile IP Phone by BWLAN

Evacuation Place  MANET  Local Government

Bi-directional Mobile IP Phone Communication

- Good voice quality
- within 240 msec time delay
Performance Evaluation of Realtime Video Streaming by BWLAN

Evacuation Place

Mobile PC server

Wireless LAN Card (802.11n)

Relay Station

Wireless LAN Card (802.11n/b/g 11b/)

PC Client 1

Video Transmission from Disaster Area

BWLAN

PC Client

Local Government

Wireless LAN Card (802.11g)

Wireless LAN Card (802.11g)
Realtime Video Streaming System over BWMN
Camera Control by Remote Operation
## Result of Video Transfer Function

<table>
<thead>
<tr>
<th>Video image</th>
<th>Omni-Directional</th>
<th>PTZ camera</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td>800x250</td>
<td>320x240</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>WMV</td>
<td>WMV</td>
</tr>
<tr>
<td><strong>Req. BW</strong></td>
<td>2 Mbps</td>
<td>1 Mbps</td>
</tr>
<tr>
<td><strong>Frame Rate</strong></td>
<td>10~15</td>
<td>10~15</td>
</tr>
</tbody>
</table>
Conclusions

In order to realize robust wide area disaster information network,
- introduced ballooned wireless mesh network
- prototyped two types of BWMN using conventional standard wireless LAN such as IEEE802.11b,g,j
- Evaluated performance of throughput, packet loss rate for both BWMSs
- Also evaluated the performance of disaster applications, including Web GIS, Wireless IP Phone and Video.
- Through the performance, verified the usefulness

Future Works

• Stabilization of Balloon in the sky against strong wind
• Simple operation miniaturization of Balloon with small number of person
• Introduction of autonomous disaster information network
Automous Disaster Information Network

- Obal shped ballooned
- Cognitive WBMS with directional antenna

- Solar Panel

- Elliptical balloon reduces wind influence
- Film type solar power for autonomous power supply
- Hexagonal antenna and high-speed wireless combination of 802.11j for horizontal multi-hop
- 802.11b,g for vertical hot spot
- Small lightweight panoramic video camera for aerial image surveillance (panning, tilting, zooming from the ground is possible)
Thank you for your attention
Quick Recovery Requirement from Failure

System functionality just after disaster is critical

System Functionality %

Minimum Functionality

Occurrence of disaster
Temporal recovery
Complete recovery

Elapsed time

This period must be shortened as possible

$t_x$
$t_y$
<table>
<thead>
<tr>
<th></th>
<th>WHAN IEEE802.11b,g</th>
<th>HWAN IEEE802.11n</th>
<th>WiMAX IEEE802.16e</th>
<th>W Access IEEE802.11j</th>
<th>Subscribe Wireless</th>
<th>Personal Wireless</th>
<th>3G Cellular Phone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freq.</td>
<td>2.4GHz</td>
<td>2.4GHz</td>
<td>~5GHz</td>
<td>5 GHz</td>
<td>22~38GHz</td>
<td>1.2GHz</td>
<td>800 MHz</td>
</tr>
<tr>
<td>MAX. Speed</td>
<td>11, 54Mbps</td>
<td>300Mbps~</td>
<td>75Mbps</td>
<td>54Mbps</td>
<td>165Mbps</td>
<td>128Kbps</td>
<td>1.2Mbps</td>
</tr>
<tr>
<td>Sig. Power</td>
<td>10mW</td>
<td>10mW</td>
<td>-</td>
<td>250mW</td>
<td>-</td>
<td>10 W</td>
<td>250mW</td>
</tr>
<tr>
<td>Max Distance</td>
<td>~5Km</td>
<td>~5Km</td>
<td>10Km</td>
<td>30Km</td>
<td>4Km</td>
<td>20Km</td>
<td>10Km</td>
</tr>
<tr>
<td>License</td>
<td>Not Required</td>
<td>Not Required</td>
<td>Required</td>
<td>Registered</td>
<td>Required</td>
<td>Required</td>
<td>Not required</td>
</tr>
</tbody>
</table>